Art. XX.—*On an Unnoticed Feature of the Faulting at Ballarat East.*

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(With Plate XXXII.).

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The Ballarat East Goldfield has been described by Mr. Ernest Lidgey, in a Special Report issued by the Department of Mines, Victoria, in 1894.

The faults are there grouped as follows:—

- Faults which occurred before and during the time when quartz veins and lodes were being formed.
- Faults which occurred after the quartz veins and lodes were formed, including—
  - Strike faults coinciding with the bedding planes.
  - Strike faults, or slides, crossing the strata in their dip. These are always reversed faults.
  - Dip faults or crosscourses.

It is to the nature of the movement on these dip-faults, or crosscourses, that I now wish especially to call attention.

Some 46 of these crosscourses are shown on a plan accompanying Mr. Lidgey's report.

He notices with reference to them that they are more recent than any of the other faults; that the down-throw is on the hanging wall side, and they are consequently normal faults, and that the apparent heave is always on the side of the greater angle, that is, the greater angle in a plan of the intersection of crosscourse and strata.

More recent observations corroborate these conclusions; but an unusual case seems to occur in the North Woah Hawp Co., of a small apparent heave in the other direction, and possibly may also occur on a few crosscourses whose strike is nearly at right angles to that of the strata.

For a number of these crosscourses the amount of the "apparent throw" and "apparent heave" is stated in a list in Mr. Lidgey's report.

Now, if it be remembered that the strata are ordinarily nearly vertical, and that the crosscourses are usually nearly vertical. it will easily be seen that the recorded throws are quite inadequate to produce the recorded heaves. The figures recorded as "apparent throw" seem to represent the actual vertical component of the displacement, as measured by the difference of level of the intersections of a recognisable vein with the indicator on the two sides of the crosscourse. Also, if the strata were actually vertical, a crosscourse, whatever its inclination, would necessarily produce a heave towards the smaller angle in plan if the real movement were a downward movement of the hanging wall in the direction of the dip of the crosscourse. (See Fig. 2).

If the strata were not quite vertical with the same movement the heave would at first diminish till it disappeared, and with a further departure of the strata from the vertical, would become an apparent heave in the opposite direction.

If the strikes of strata and crosscourse make an angle of 60° with one another, strata with a dip equal to that of the crosscourse would be heaved towards the greater angle to the same amount as vertical strata would be heaved toward the smaller angle in plan.

From these facts we must conclude that the movement has not been a downward movement of the hanging wall side in the line of dip of the crosscourse. The vertical component of the movement is indeed, at least usually, downward on the hanging wall side; but it does not even approximately represent the whole actual movement. The description of the crosscourses as normal faults is therefore not incorrect, but is certainly quite inadequate.

It is possible that this is the reason why the term "apparent throw" is used in Mr. Lidgey's report. The alternatives of incorrect correlation of the strata, undetected repetition, or exceptional dips are quite out of the question. They could not explain a consistent feature of so many crosscourses throughout the field.

The "apparent throw," then, represents the actual vertical component of the displacement. The "apparent heave" is, however, composed of two parts, one of which, relatively small, is consequent on this vertical movement, and the other, relatively large and usually in the opposite direction, is due to an actual horizontal component of the displacement on the fault.

It is not uncommon for the "apparent throw" and "apparent heave" to be about equal, though the throw is in some cases much less. The following table gives approximately the amount of the heave due to the vertical displacement and the amount of the observed heave, and the amount of heave due to the horizontal movement as deduced from these. No. 21, being a north-westerly crosscourse, shows a left-hand heave, the others are north-easterly and show a right-hand heave.

Crosscourse.	No. 3.	13.	19.	21.
"Apparent throw" -	150	60	4	14
Consequent heave - -	10 left	7 left	.03	1 right
Observed heave - -	180 right	80 right	4	14 left
Heave due to horizontal movement - -	190 right	87 right	4	15 left

In addition to these it may be noted that on the great crosscourse No. 34, 100 feet vertical displacement would give only 6 feet heave, and that to the left if the hanging wall had gone down. The observed heave is 612 feet to the right. In No. 19, 100 feet vertical displacement would give less than a foot heave, but in No. 37, where the conditions are such as to produce an unusually large heave, the same vertical displacement would give about 58 feet heave in vertical strata, with the ordinary average strike of this field.

Crosscourse No. 23 is noted by Mr. Lidgey as producing the same heave, on the indicator, and on four crosscourses intersected by it. This result could only be due to horizontal movement, but the heave is small, and appears to be irregular in amount.

The evidence of the slickensides.—The walls of the crosscourses and partings parallel to the walls in the fault-rock are often well striated. These can usually be seen running in a variety of directions, but on the crosscourses the most marked and most persistent seem generally nearer to a horizontal direction than to the line of dip of the surfaces, and are often almost horizontal. The evidence of the striations supports the deductions from the apparent throw and heave, but is itself less consistent, owing, no doubt, to the fact that strong striations may result from a single movement which may be itself of small importance compared with the whole movement, and different in direction.

It is noticed by Mr. Lidgey, that the north-easterly crosscourses of this field are most numerous and appear most important, several of them have larger displacements than any known north-westerly crosscourse. On the north-easterly crosscourses, the hanging wall side has generally a relative movement downward and forward in a south-westerly direction. This is the general direction of dip of most of the slides. The crosscourses are, however, newer than the slides and displace them, but the existence of the slides may have facilitated the movement in this direction, and contemporaneous further movement on the slides might easily produce an abrupt change in the displacement on the crosscourses.

The other faults.—The slides are in all cases reversed faults, and the strata are usually much bent near them. If we regard the strata as vertical and the movement as along the line of dip of the fault, then the heave due to any throw = throw × co-tangent of angle of inclination of fault to horizontal plane × cosine of angle between strikes of fault and strata. As the angle of inclination of the fault is usually about 45°, and the angle between the strikes usually less than 10°, both these ratios are nearly unity, and we would expect to find throw and heave about equal, as they are by observation. But it does not appear how the throw has been ascertained; if it is simply the difference of level of the two points in a vertical plane at which the indicator (or any other bed) meets the fault from the upper and lower sides, then it must necessarily agree with the apparent heave of the same bed, for (as is shown later by Fig. 1), the two quantities are not independent. Similar remarks apply to other strike-faults of which the direction and dip are different. The observed facts are in any case not inconsistent with a typical reversed fault, and the striations, in some cases at least, support the view that the motion has been in the direction of the line of dip of the fault.

There does not appear to be any very real difference between these slides and those which occurred prior to the formation of the quartz reefs, some of which are themselves occupied by quartz reefs. The periods of formation of the strike faults and of the quartz veins and lodes appear to have overlapped.

Effect of the crosscourses and other faults on the position of rich ore.

The change of value or dimensions of ore on crossing a fault are in many cases directly due to the fact that the ore, where first recovered, is not the part severed from that portion of the lode at which the fault was met. At Ballarat East, however, the actual veins lost are usually recoverable at no great difference of level on the other side of a crosscourse. The difficulty in ascertaining the throw is often due to the large number of veins of not very different character, and the fact that in working they are soon removed. The correct correlation of rich and poor portions in neighbouring fault blocks can only be made by taking account of the actual movement.

The indicator belt as at present known terminates abruptly at Crosscourse No. 1, Black Hill. It seems unlikely that any rich continuation on the surface could have so long escaped detection. It may be that the faulting has brought up to the surface level a poor portion of the indicator. [Some of the veins crossing the indicator run from a slide on which may be a "main lode." Such series of veins form oblique bands, and, if the slide is too far from the indicator, may not reach it at all, though they may be worked on other slates. Some of the unworked portions of the indicator are due to this arrangement, and some very rich specimens recently found at the North Woah Hawp Co. were found where one of these slides crossed the indicator]. Another explanation of its absence may be that strike faults, being reversed faults, leave a gap in the indicator between certain levels. If the fault and strata have almost the some strike a particular bed or series of beds may be absent at the surface for a long distance.

Geometrical constructions to ascertain the true movement on the fault, or to recover a lost lode, or other deposit, displaced by a fault.

In Figs. 1 to 4, supposed drawn on a horizontal plane:

Let ROF be the line of strike of the fault;

DO the line of strike of the lode on the side where already known;

RE the position of the lode on the other side of the fault;

OI, RJ the projections on the horizontal plane of the lines of intersection of the two parts of the lode with the fault.

[For convenience, the word "lode" will be used for the faulted deposit, except where some special case is referred to. The construction will apply equally to a bed or to an older fault-line].

The arrows on the lines of strike represent direction of dip; those alongside other lines represent the direction of inclination of the inclined lines, which these lines on the plan represent.

ON drawn at right angles to OF is the projection on the horizontal plane of the line of dip of the fault.

OI may be thus ascertained: Take a point B on OF, and make angles OBA, OBC, equal to the angles which the fault and the lode respectively make with the vertical. Then in a height OB the fault and lode will move in the directions of their dips to distances measured on a horizontal plane by OA and OC respectively. Draw lines (shown by dotted lines in Fig. 1) parallel to OF and OD, and at distances from them equal to OA, OC respectively. Their intersection is a point on the intersection of the lode and fault, which can be then at once drawn. If there is no rotation round an axis perpendicular to the plane of the fault, the dip and strike of the lode beyond the fault should be unaltered (neglecting any bending due to the movement, as is done here throughout), RJ is therefore parallel to OI. If there has been rotation, RJ needs to be plotted independently.

Then, since RJ represents all points on the intersection of the fault and the lode beyond the fault, the point once in contact with O must have moved to some point represented in plan on the line RJ.

If the movement has been down the line of dip, this point will be given by M (on the line ON), otherwise it may be at some other point such as Q. OQ represents, on plan, the movement of the point once in contact with O.

To determine Q.: On the crosscourses at Ballarat East it is often possible to ascertain directly the difference of level of the points at which some recognisable vein crosses the indicator on the two sides of the crosscourse. This is the true throw or vertical component of the movement. If OB be taken equal to this throw, then OA represents the amount of displacement on plan in the direction of the dip, and if AQ be drawn parallel to OR to meet RJ in Q, the true movement is thus determined as a true throw = OB, and a true lateral displacement = AQ. Fig. 1 shows a general case; Fig. 2, the particular case of a vertical lode or bed. Fig. 2 represents the case at Ballarat East, and it will be seen that the vertical movement alone would give an apparent lateral displacement OW, whereas the observed lateral displacement is almost always in the opposite direction. [For clearness in the figure, OA is much larger, compared with AQ, than in most actual cases at Ballarat East].

The construction in Fig. 3: Ascertain Q by the observed heaves of two non-parallel lodes (lode and beds, etc.). Od, OD represent their directions of strike, not necessarily actual position. Or, OR their observed amounts of displacement along the fault. Rj, RJ the lines of intersection with fault of their parts beyond the fault. If these meet at Q, the true direction of movement is shown on plan as OQ, and may, if desired, be resolved into two components as before.

From Fig. 4, which represents a case where there has been rotation, it will be seen that two points, O, I, are not displaced, either to the same amount or in the same direction. The determination of a rate of variation of both components of the movement may be made by sufficient observations, and it is evident that either or both components may at some point vanish, and will do so if other conditions remain the same for a sufficient distance.

The same constructions may be used when the motion on the fault is known in direction or amount, or both, to ascertain the direction and distance at which the lode may be recovered on the same level as the point at which it was lost.

Zimmerman's rule depends on a construction of this kind. If the line of intersection OI and a perpendicular ON to fault-line be both drawn forward into the unknown ground, the lode is to be sought on that side of the line of intersection on which this perpendicular falls. This is illustrated in Fig. 1, where it gives the correct direction, and in Fig. 2, where it would give the wrong direction.

Fig. 3 also at once shows that, if the lateral displacement of the lode OD is observed as OR, and it is desired to ascertain that of Od, it is not immaterial to which point on RJ we suppose the point from O to have moved.

Zimmerman's rule is, in fact, dependent on the following assumptions:—

(i). That the relative movement of the hanging wall side has been downward on the line of dip of the fault (that is, that it is represented on plan by ON).

(ii). That there has been no relative rotation about an axis perpendicular to the plane of the fault.

(iii). That there has been no alteration of shape which would make the two blocks no longer correspond to one another.

A modified rule has been suggested by Mr. J. T. Freeland (Trans. Amer. Inst. M.E., vol. xxi.). "After cutting through the fault prospect on that side of the line of intersection of the known parts of the vein and fault, indicated by the relative motion of the opposite block of ground for the extension of the vein and the second line of intersection." The first line of intersection is here drawn towards the unknown ground, and the "relative motion of the opposite block" is indicated by its projection on the horizontal plane of the diagram (the line OQ on the figures).

This completely disposes of the first assumption, and hence gives the correct direction in the case of Fig. 2. The second assumption is also disposed of if it is possible to ascertain the direction of the line of intersection (on plan) of the fault with the lost part of the deposit.

It seems better, however, to use a geometrical construction without putting it as a rule, as this tends to the forgetting of assumed conditions.

The lode and fault being plotted as DO, OF, draw OQ representing the projection on the horizontal plain of the direction of movement, and QR parallel to the projection of the line of intersection of the fault and the lost portion of the lode. Let QR meet FO in R, then OR is the direction in which to seek the lost lode, and if OQ represents the amount of the movement, OR represents, on the same scale, the distance to be driven.

The absence of rotation in stratified rocks is usually at once ascertainable as soon as settled ground is reached beyond the fault. If there has been rotation, the line of intersection is easily plotted in the case of bedded rocks, or of a lode parallel to the beds, but for other cases may be more easily given by another construction following. If the rotation is small it can often be neglected, but may affect the direction to be driven when the line of intersection and the direction of movement make only a small angle with one another.

The direction of striations, if sufficiently decisive, may be used to determine the direction of movement—determining the ratio of OB to AQ.

The diagram on a horizontal plane is especially useful in working lodes; as DO, OR, RE usually represent actual drives, and the line of intersection is sometimes ascertained by the positions of lode and fault at a lower level.

Plans on the plane of the fault may also be used, and are chiefly convenient as showing at once on the diagram the angle which the striations should make with the horizontal line in the fault, and for the ease with which they deal with rotations, though Mr. P. Lake, who uses this construction to ascertain the true movement on a fault (Geol. Mag. 1897) states that in the case of a rotation the problem is insoluble.

Figs. 5 to 8 illustrate such diagrams.

OF is a horizontal line in the fault-plane.

OH, RL are traces of the planes of the lode on the fault-plane.

OP is the direction and amount of movement.

In Fig. 5, OD, OI, drawn as on a horizontal plane with OF, represent the strike of the lode and the projection of its line of intersection.

IG is drawn perpendicular to OF, FI making angle GFI equal to the inclination of the fault to the vertical, GH = IF. Then OH is determined. In the absence of rotation RL is parallel to OH.

If, however, it is found that on passing the fault the trace of otherwise parallel bedding planes is altered from OH to OK, this rotation, due to movement on the fault, will affect also to the same amount lodes, etc., crossing these beds. A lode, whose trace on this side of the fault was parallel to PT (Fig. 6) will be turned to Pr.

The true movement is ascertainable as before. Fig. 5 represents the case of a horizontal recognisable vein crossing the bed, represented by OH. UV evidently represents the actual movement, and is easily resolved into two components as before.

Fig. 7 represents two non-parallel lodes. OH, Oh, the directions of their traces on this side of the fault OR, Or, the amount of their observed displacements along the fault. RP, rP, the directions of their traces on the fault plane on the other side. Then the true movement is given by OP. Mr. P. Lake uses this construction for the displacement of an anticline. Rotation presents no difficulty in bedded rocks, for its amount is at once ascertainable, and if there had been observed displacement to OS, os, with a rotation represented by the angle SPR, or sPr, the construction to fix P would be still as easily made.

Fig. 8 represents a diagram to deduce the movement of a point X from that of O, when there is rotation the line OX may be supposed displaced parallel to itself to PZ, and then rotated about P to PY, then XY will represent the actual movement of the point once in contact with X, the rotation remaining the same.

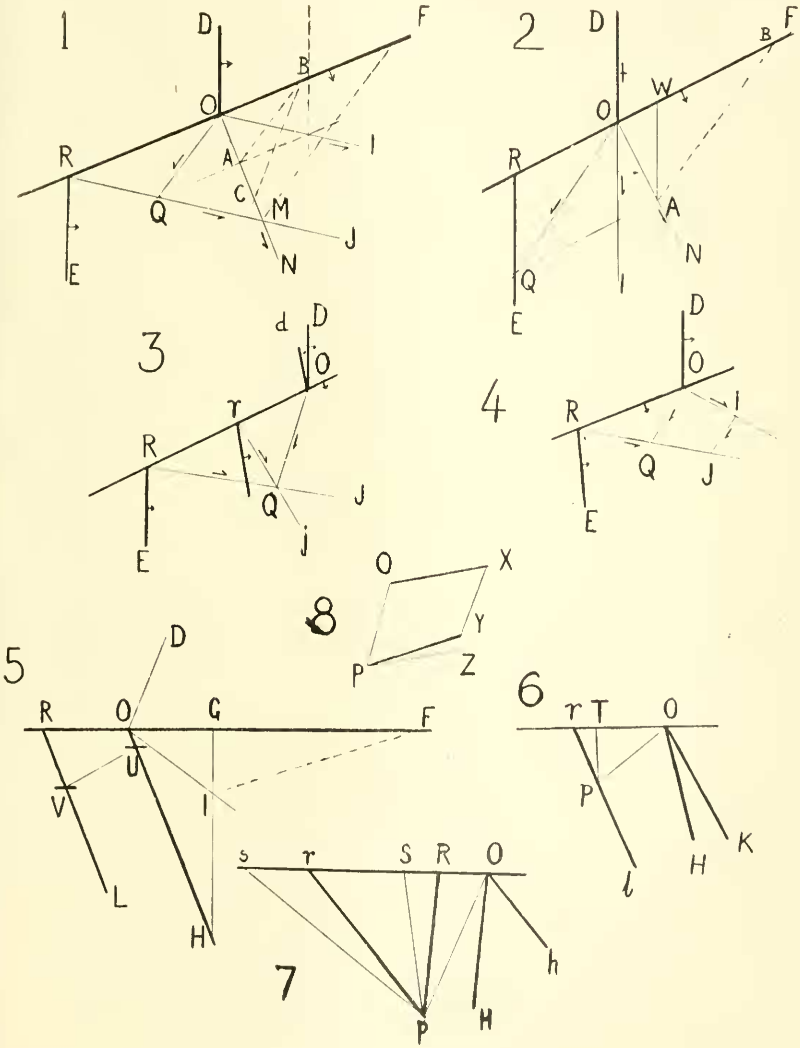
Cases of alteration in shape of either block (as by a fault meeting the first fault, or any other cause) need to be each treated as suits the individual case. In the case of intersecting faults it may be convenient to examine the movement along and at right angles to their line of intersection.

The complete description of the movement in a fault comprises three parts—the throw, the true lateral displacement, and the rotation. With a rotation, the throw and lateral displacements will vary from point to point, and all may vary with an alteration of shape of one block either gradually or suddenly.

Formulae for calculation might be given for all these cases, but the calculation would be usually more troublesome than the diagram, and the diagram can be easily made as accurate as the data themselves, on which a calculation would have to be based.

A case is, perhaps, worth referring to which may occur, but is scarcely a true case of faulting. It may happen that the deposition of lode matter has gone on under similar conditions in two fractures meeting a fault from the two opposite sides. The lodes produced may be similar; the fractures which they occupy are independent, and there may be apparently throw, heave, or rotation, whereas really there is only a similarity between two distinct lodes occupying fractures which never have corresponded.

The crosscourses of other fields have not been described with the same detail as those of Ballarat East. It seems, however, that a similar oblique motion, as might be expected, is found in



Fault Diagrams.